# Embankment Construction

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# Welcome

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Federal Highway Administration

# Overview

## Course Objectives

- Embankment Techniques
- Testing
- Dealing with “wet” material

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# Embankment Techniques

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# Embankment Techniques

- Embankment Foundation Preparation
- Embankment Construction
- Compaction

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# First things first!!

- Timing Restrictions (Subsection 107 & 108)
- Erosion Control Devices (BMP's)
- Traffic Control Devices and Flaggers
- Surveying and Staking
- Clearing and Grubbing
- Topsoil Removal
- Are there any environmentally sensitive areas nearby that need special attention? (I.e., wetlands, bald eagle nests, etc.)

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# Subsurface Drainage

- Essential to Road Life
- Reduces Future Maintenance Costs
- If unexpected moisture is encountered, and corrective measures are not included in the plans (I.e., underdrains, subexcavation, etc.) notify the PE immediately.

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# Preparation is Everything!

- Embankment quality depends on proper foundation preparation.
- Conditions that may cause embankment failures:
  - Subsurface slippage planes
  - Soft or unsuitable materials
  - Springs or seepages
- Embankment Failures – Construction Manual Chapter 9

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# Embankment Foundation Preparation

- Fills less than 1 meter over natural ground
  - Break up the cleared ground surface to a minimum depth of 150 mm.
    - Scarify or plow
  - Compact natural ground according to 204.11.

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# Embankment Foundation Preparation (continued)

- Shallow fills (less than 0.5 meters) over an existing asphalt, concrete or gravel road surface.
  - Scarify or pulverize
    - Gravel roads - 150 mm minimum depth
    - Asphalt or Concrete - To a minimum depth of 150 mm below existing mat.
  - Reduce all particle sized to a maximum of 150 mm
    - Produce a uniform material
  - Compact the surface according to 204.11.

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# Embankment Foundation Preparation (continued)

- Embankments across ground that will not support equipment.
  - End dump a uniform layer of embankment material.
  - Limit layer thickness to the minimum depth necessary to support equipment.
  - Monitor the use vibratory rollers, as they may weaken the shear strength of the supporting soils, and lead to failure of the natural ground.

# Embankment Foundation Preparation (continued)

- Embankments on existing slopes steeper than 1v:3h
  - Cut horizontal benches in the existing slope wide enough to accommodate both placement and compaction operations.
  - Begin each bench where original ground intersects with the vertical cut of the previous bench.

# Embankment Construction

- Determine the suitability of the embankment material.
  - AASHTO M 145
- If suitable material is not available, utilize unclassified borrow. (704.06)
  - Granular material free of excess moisture, muck, frozen lumps, root, sod, or other deleterious material.
  - Maximum dimension - 600 mm
  - AASHTO M 145 Classification – A-1, A-3, or A-2-4

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CLASSIFICATION OF HIGHWAY SUBGRADE MATERIALS
(With suggested subgroups)

| General Classification | Granular Materials (35% or less passing No. 200) | | | | | | | Silt-Clay Materials (More than 35% passing #200) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group Classification | A-1 | | A-3 | A-2 | | | | A-4 | A-5 | A-6 | A-7 |
| | A-1-a | A-1-b | | A-2-4 | A-2-5 | A-2-6 | A-2-7 | | | | A-7-5<br>A-7-6 |
| Sieve Analysis, Percent Passing: | | | | | | | | | | | |
| No. 10 | 0-50 | | | | | | | | | | |
| No. 40 | 0-30 | 0-50 | 51-100 | | | | | | | | |
| No. 200 | 0-15 | 0-25 | 0-10 | 0-35 | 0-35 | 0-35 | 0-35 | 36-100 | 36-100 | 36-100 | 36-100 |
| Characteristics of fraction passing # 40: | | | | | | | | | | | |
| Liquid Limit | | | | 0-40 | 41+ | 0-40 | 41+ | 0-40 | 41+ | 0-40 | 41+ |
| Plasticity Index | 0-6 | | N.P. | 0-10 | 0-10 | 11+ | 11+ | 0-10 | 0-10 | 11+ | 11+ |
| Group Index | 0 | | 0 | 0 | | 0-4 | | 0-8 | 0-12 | 0-16 | 0-20 |
| Usual Types of Significicant Constituent Materials | Stone Fragments, Gravel and Sand | | Fine Sand | Silty or Clayey Gravel and Sand | | | | Silty Soils | | Clayey Soils | |
| General Rating as Subgrade | Excellent to Good | | | | | Fair to Poor | | | | | |

| Soil | Visual | Moist Sample | Soil ribboned between thumb and finger when moist. |
|---|---|---|---|
| Sand | Individual grain size is detectable. It is free flowing when dry. | Forms a cast that crumbles when lightly touched. | Cannot be ribboned. |
| Sandy Loam | Granular soil with sufficient silt and clay to make it somewhat coherent. Sand predominates. | Forms cast that not break with careful handling. | Cannot be ribboned. |
| Loam | Uniform mixture of sand, silt and clay. Gritty feel but is fairly smooth and slightly plastic. | Forms a cast that can be handled without breaking. | Cannot be ribboned |
| Silt Loam | Has a moderate amount of finer grades of sand, small amount of clay and over half the particles are silt. When dry may appear Cloddy which can be broken And pulverized into powder. | Forms a cast that can be handled. When wet soil runs together and puddles. | Will ribbon but has broken Appearance and feels smooth. Maybe slightly plastic. |
| Silt | Contains over 80% of silt particles with very little sand and clay. when dry it maybe cloddy, readily pulverizes to power with a flour like feel. | Forms a cast that can be handled. When wet it puddles. | Tendency to ribbon with Broken appearance and feels smooth. |
| Clay Loam | Fine textured soil breaks into hard lumps when dry. Contains more clay than silt loam. Looks like clay in dry form. Identify by physical behavior when moist. | Forms cast that can be handled without breaking. Can be worked into a dense mass. | Forms a thin ribbon which breaks easily. Barely sustains its own weight. |
| Clay | Fine textured soil breaks into hard lumps when dry. Difficult to pulverize into flourlike powder. Identify by physical behavior when moist. | Forms cast that can be handled without breaking. | Forms long thin flexible ribbon. Can be worked into a dense compact mass. extremely plasticity. |

# Embankment Construction

- Daily embankment surface treatment
  - Compact and shape surface to uniform cross section.
  - Eliminate all ruts and low spots that could hold water.
- Compact side slopes with at tamping type roller or dozer walking.
  - For 1:1.75 or steeper slopes – compact the slopes as construction progresses.
- To aid in compaction, route construction equipment over full width and length of embankment.

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# Embankment Construction

- Rock is material containing 25% or more, by volume, rock particles greater than 100 mm in diameter.
- Compacted Lift thickness – 300 mm maximum
  - 600 mm lift allowable if material is composed predominantly of boulders or rock fragments too large for 300 mm lift
- Rock layers must contain sufficient small rocks and earth material to fill the voids.
- Construct top 300 mm of embankment with topping or other suitable material.

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# Embankment Construction

- Place individual rock fragments and boulders greater than 600 mm in diameter by:
  - Distributing rock within the embankment to prevent nesting and fill the voids between them with finer material.
- Reduce rock to less than 1200 mm in the largest dimension
- Compact each layer according to 204.11.

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# Embankment Construction

- Earth is material containing less than 25%, by volume, rock particles greater than 100 mm in diameter.
- Maximum compacted lift thickness - 300 mm

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# Compaction

- What is compaction?

ASTM Definition - The densification of a soil by means of mechanical manipulation.

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# Compaction

- “On the grade” Definition

Put more stuff in a smaller space by using some type of equipment

# Compaction

- Lower Embankment Section
  - Prevent settlement and provide slope stability.
- Upper Embankment Section
  - Provide bearing capacity, control volume changes, and provide uniformity for aggregate courses.

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# Compaction

- Soil
- Water
- Air

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# Compaction

## Volume & Weight Relationship

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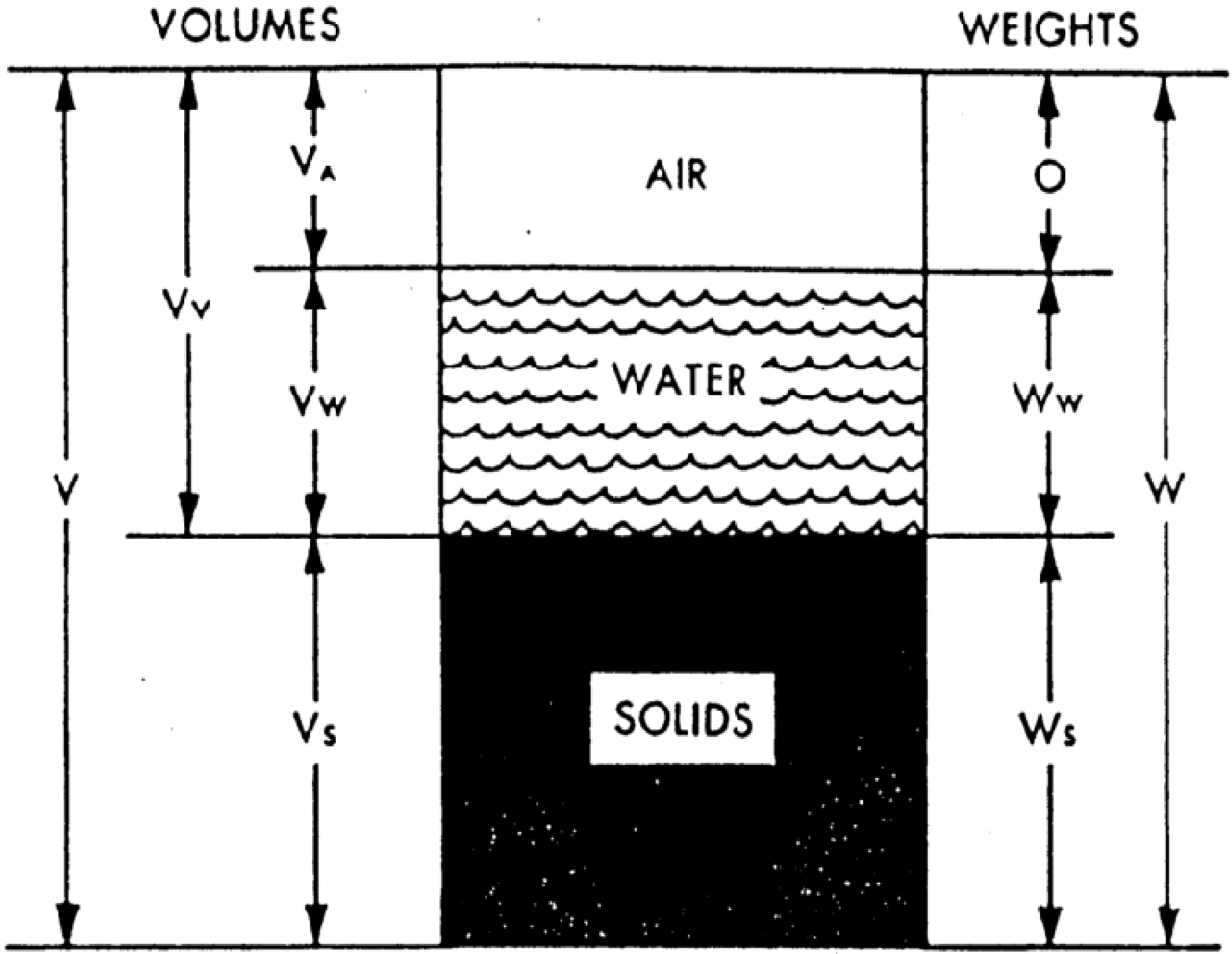


*Figure II-2.*

*Schematic diagram showing three phases of a soil.*

# Compaction

Moisture Content -

$$W(\%) = (W_w / W_s) * 100$$

Where:

$W_w$ = weight of water

$W_s$ = dry weight of solids

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# Compaction

Dry Unit Weight -

$$Y_d = W_s / V$$

Where:

$W_s$ = dry weight of solids

V = total volume

# Compaction

Wet Unit Weight -

$$Y_t = (W_s + W_w) / V$$

Where:

$W_s$ = weight of solids

$W_w$ = weight of water

$V$ = total volume

# Compaction

Degree of Saturation

$$S = V_w / V_v$$

Where:

$V_w$ = volume of water

$V_v$ = volume of voids

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# Testing

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# Compaction

- AASHTO T 180
- AASHTO T 99
- Humphries ***granular*** compaction

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| Sieve Analysis, Percent Passing: | | | | | | | | | | | |
| No. 10 | 0-50 | [illegible] | [illegible] | | | | | | | | |
| No. 40 | 0-30 | [illegible] | [illegible] | [illegible] | | | | | | | |
| No. 200 | 0-15 | [illegible] | [illegible] | [illegible] | 0-35 | 0-35 | 0-35 | 36-100 | 36-100 | 36-100 | 36-100 |
| Characteristics of fraction passing # 40: | | | | | | | | | | | |
| Liquid Limit | | | | 0-4 | [illegible] | [illegible] | 41+ | 0-40 | 41+ | 0-40 | 41+ |
| Plasticity Index | 0-6 | | N.P. | 0-1 | [illegible] | [illegible] | 11+ | 0-10 | 0-10 | 11+ | 11+ |
| Group Index | 0 | | 0 | [illegible] | | | | 0-8 | 0-12 | 0-16 | 0-20 |
| Usual Types of Significicant Constituent Materials | Stone Fragments, Gravel and Sand | | Fine Sand | S… and | | | | Silty Soils | | Clayey Soils | |
| General Rating as Subgrade | Excellent to Good | | | | | | | Fair to Poor | | | |

AASHTO T180
Method D

AASHTO T99
Method C

FOR ALL
OTHERS

# AASHTO T 99

- 5 ½ pound rammer
- Dropped from a height of 12 inches
- Uses 4 or 6 inch molds
- Rigid base to compact upon (block of concrete)

# AASHTO T 99 Method A

- Performed on material passing #4 (4.75 mm) sieve
- Compacted in 3 lifts
- 25 blows per lift
- Uses 4 inch mold (volume of 1/30 of a cubic foot)

# AASHTO T 99 Method B

- Same as Method A <u>EXCEPT</u>
  - Uses 6 inch mold (volume of 1/13.33 cubic foot)
  - 56 blows per lift

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# AASHTO T 99 Method C

- Performed on material passing 3/4 inch (19 mm)sieve
- Optional replacement of coarse material
- Compacted in 3 lifts
- 25 blows per lift
- Uses 4 inch mold

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# AASHTO T 99 Method D

- Same as Method C EXCEPT
  - Uses 6 inch mold
  - 56 blows per lift

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# AASHTO T 180

- Same as AASHTO T 99 EXCEPT
  - Uses a 10 pound rammer
  - Dropped from a height of 18 inches
  - Material is placed in 5 lifts

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# Moisture Density Curve

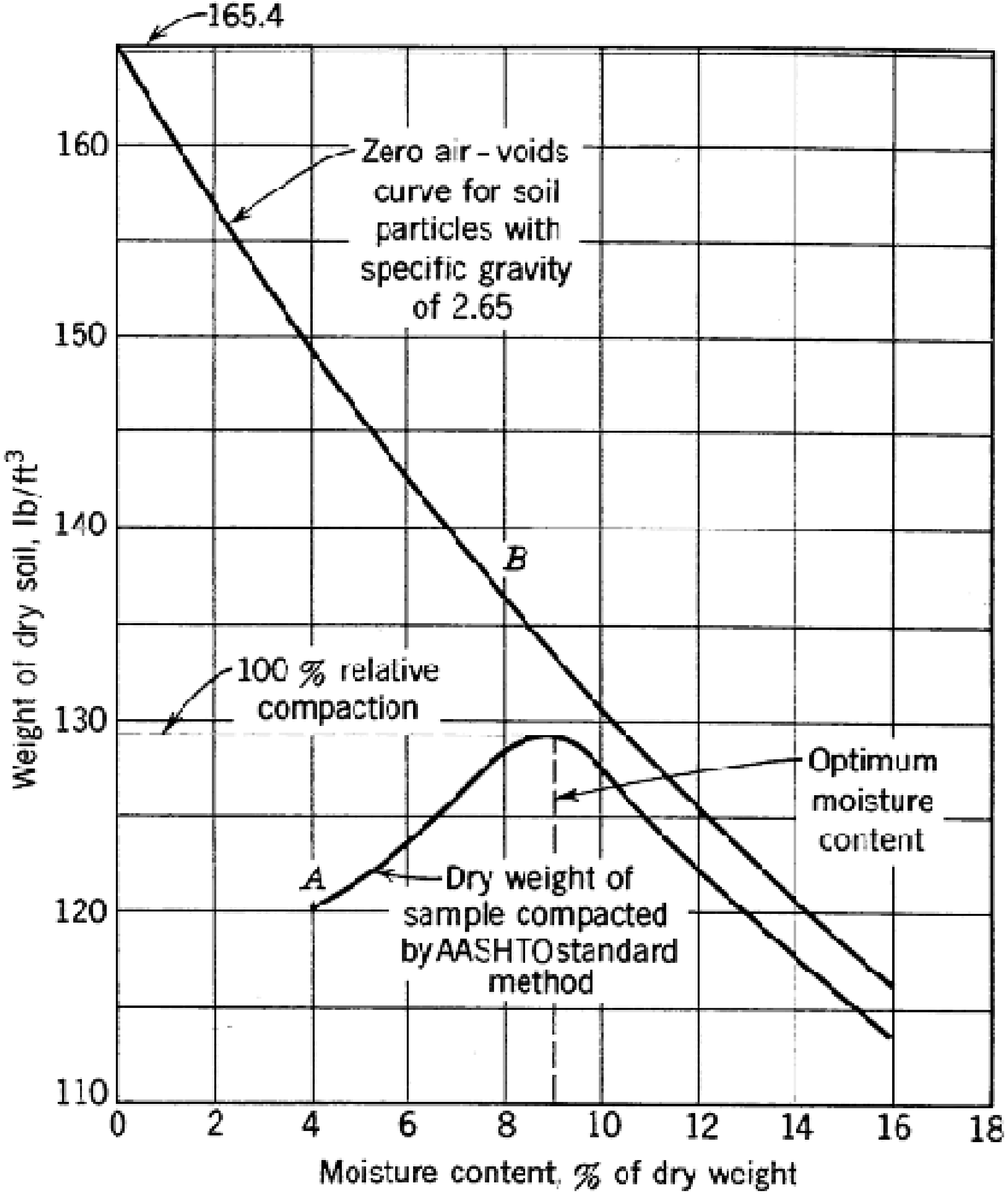


Fig. 14–5. Typical moisture–density relationships.

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# Worksheet for Determining Moisture/Density Relationships
## AASHTO T 99 AND AASHTO T 180

Project: ______ Source: ______

Where sampled: ______ Quantity represented: ______

Sample of: ______ Lot No. ______ Sample No. ______

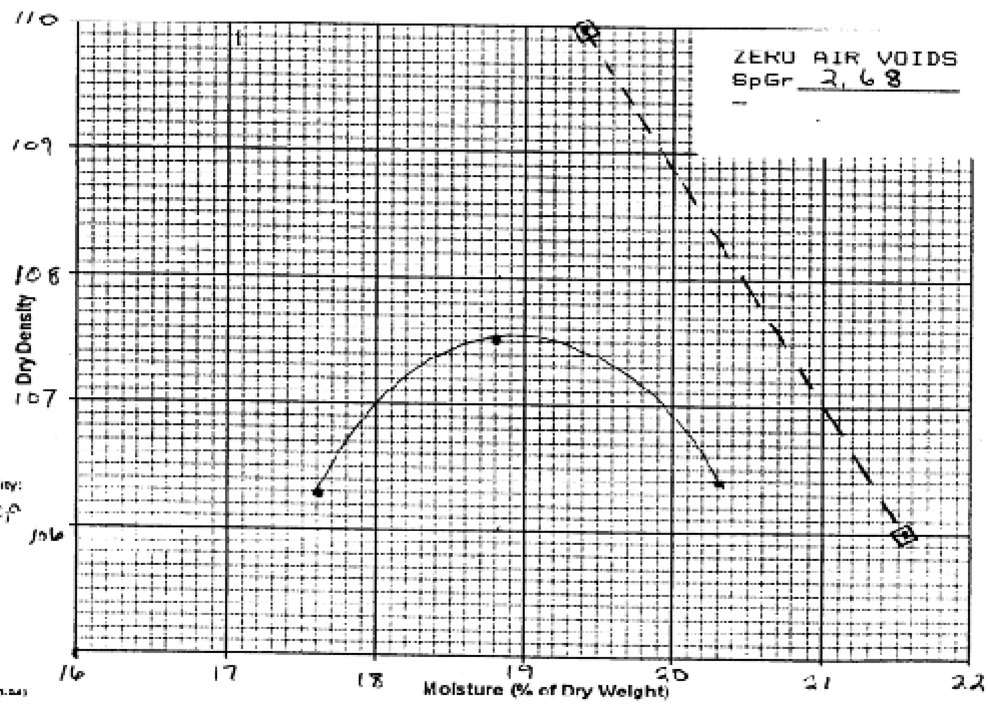
Sampled by: ______ Date: ______ Tested By: ______ Date: ______

AASHTO T 99 ☒ AASHTO T 180 ☐ Method ☐ A ☐ B ☒ C ☐ D

| Density Determination | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test No. → | 1 | 2 | 3 | | | | |
| (a) Wet soil + mold tare [kg] | 7201.5 | 7248.7 | 7254.1 | | | | |
| (b) Mold tare [kg] | 5319.6 | 5319.6 | 5319.6 | | | | |
| (c) [a - b] Wet wt. [kg] | 1887.9 | 1929.1 | 1934.5 | | | | |
| (d) Wet density (*)c [kg/m³] | 124.98 | 127.71 | 128.07 | | | | |
| Dry density [kg/m³] | 106.25 | 101.52 | 106.42 | | | | |

* For molds within tolerance, use a constant factor 1059.43 for methods A and C or 470.74 for methods B and D.

| Moisture Determination | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pan No. → | 36 | 10 | 56 | | | | |
| (r) Wet soil wt. + tare [g] | 520.8 | 557.4 | 532.5 | | | | |
| (s) Dry soil wt. + tare [g] | 487.7 | 516.7 | 493.2 | | | | |
| (t) Tare [g] | 300.0 | 300.0 | 3.00 | | | | |
| (u) Dry soil wt. [s - t] [g] | 187.7 | 216.7 | 193.2 | | | | |
| (v) Water wt. [r - s] [g] | 31.1 | 40.7 | 39.3 | | | | |
| (w) Moisture ($\frac{v}{u}$(100)) [%] | 17.6 | 19.8 | 20.3 | | | | |




Maximum Dry Density:
107.5 PCF

Optimum Moisture:
18.9 %

Form FHWA 1675 (Rev 7-94)

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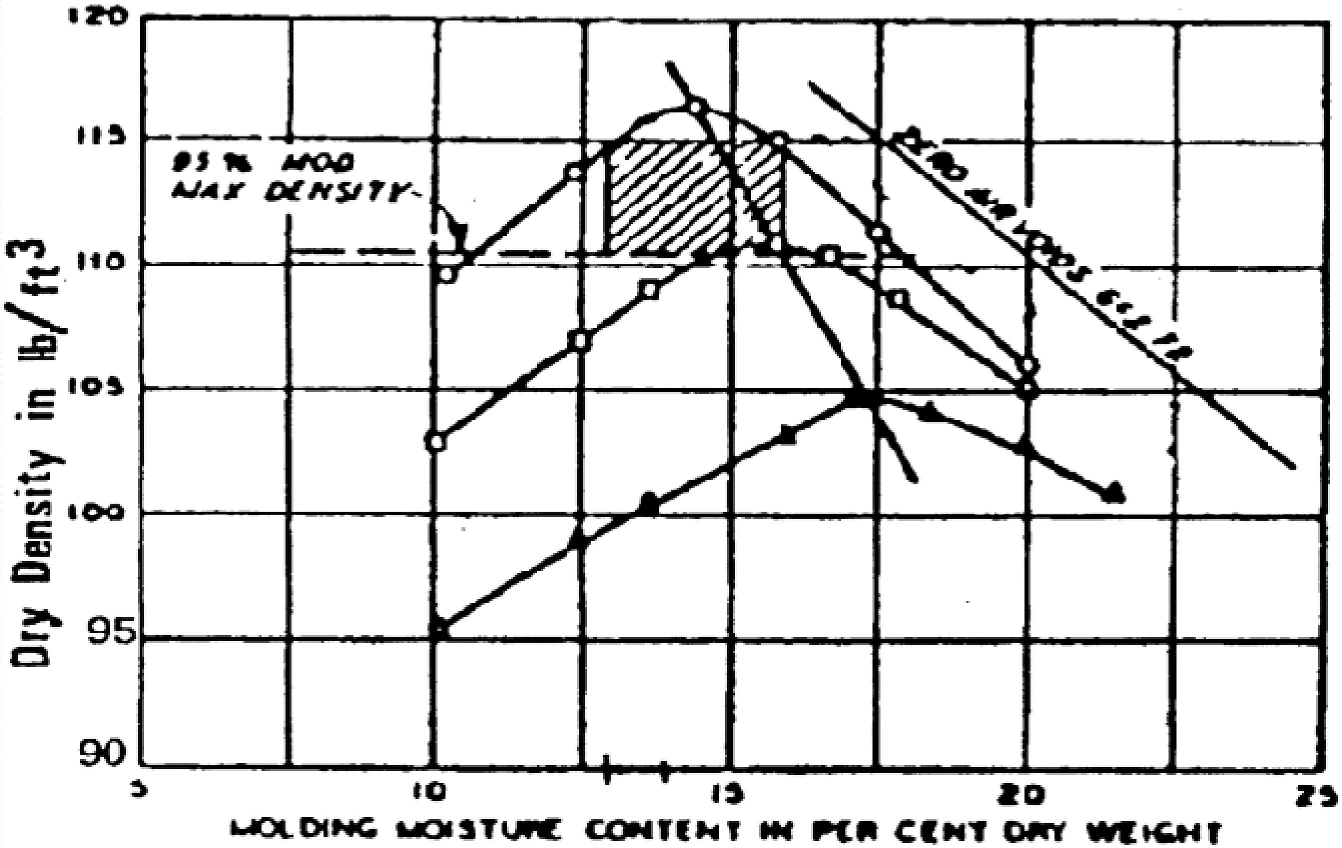


LEGEND

- o 56 BLOWS PER LAYER
- ▫ 25 BLOWS PER LAYER
- △ 10 BLOWS PER LAYER

SILTY CLAY (CL)

LI = 37

PI = 14

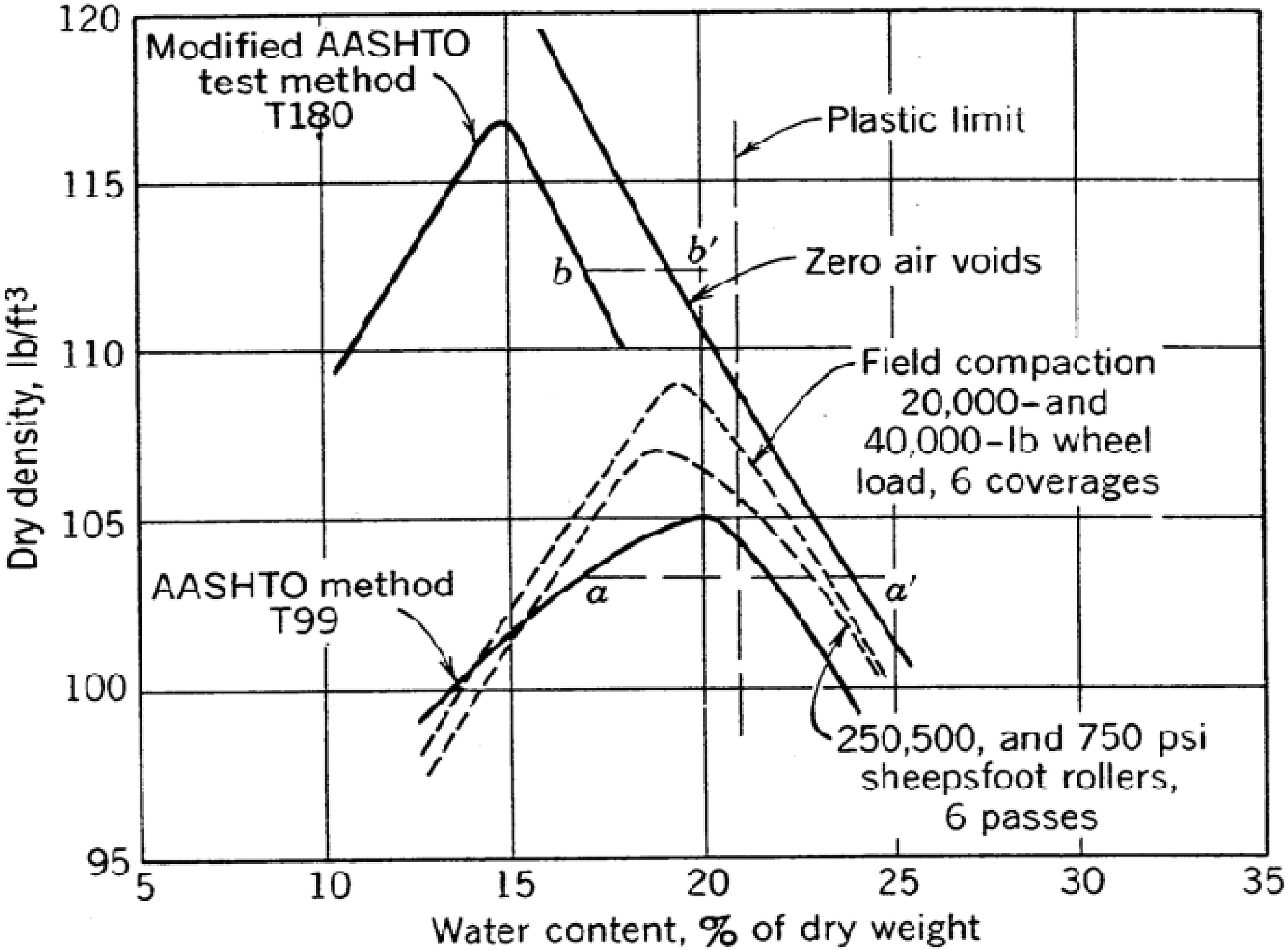


**Fig. 14–7.** Effect of compaction method on moisture–density relationships. Tests made on a silty clay soil having 10% sand, 63% silt, 27% clay; LL=36, PI=15, Sp. gr= 2.72 (modified after A. W. Johnson).

# Humphries ***GRANULAR*** Compaction

- Very Old Test Method
- Performed in the Central Lab
- Utilizes Vibration versus “Blows”
- More Dynamic Results
  - Variable - Percent Passing #4 Sieve

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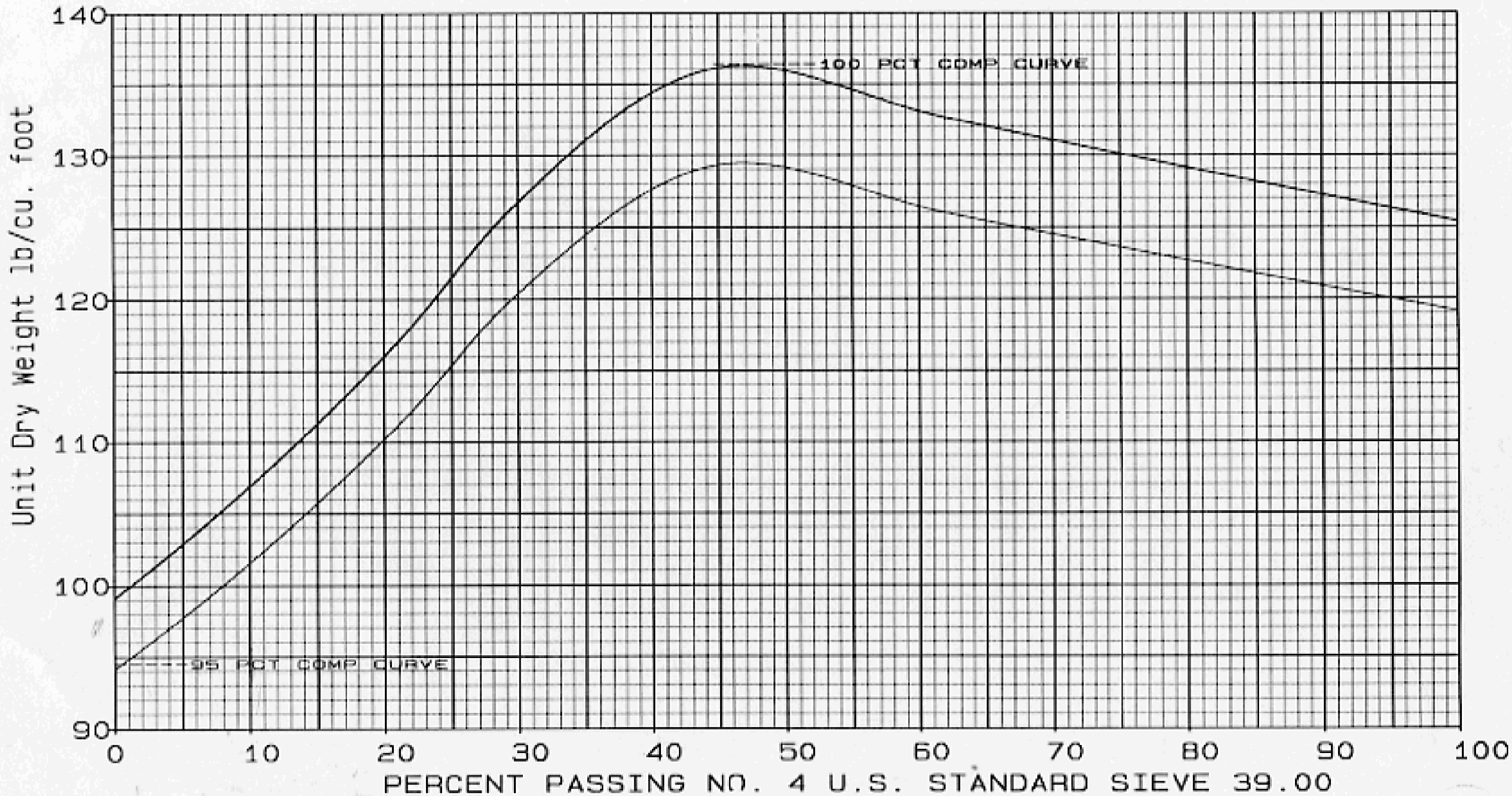
Canyon to Tower

MAXIMUM DENSITY FOR GRANULAR MATERIALS

| DENSITY SOLID | | | | DENSITY COMPACTED | | | | DENSITY LOOSE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coarse | 164 | Fine | 167 | Coarse | 99 | Fine | 125 | Coarse | 82 | Fine | 81 |

Lab. Control No. W-03-1068-AG    Tested By bh/ws    Date 11/13/2003

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| R | 22 | 118 | O | 29 | 126 | M | 45 | 136 | N | 62 | 133 |




Estimated \sture Content 5.75

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# Effects of Cold Weather

- Critical Temperature
  - 32 Degree Fahrenheit
  - Can be an immense decrease in the maximum dry density.
  - 3-part system changes to 2-part system
  - From soil, water, and air to frozen soil and air
- Study performed in 1957-1958

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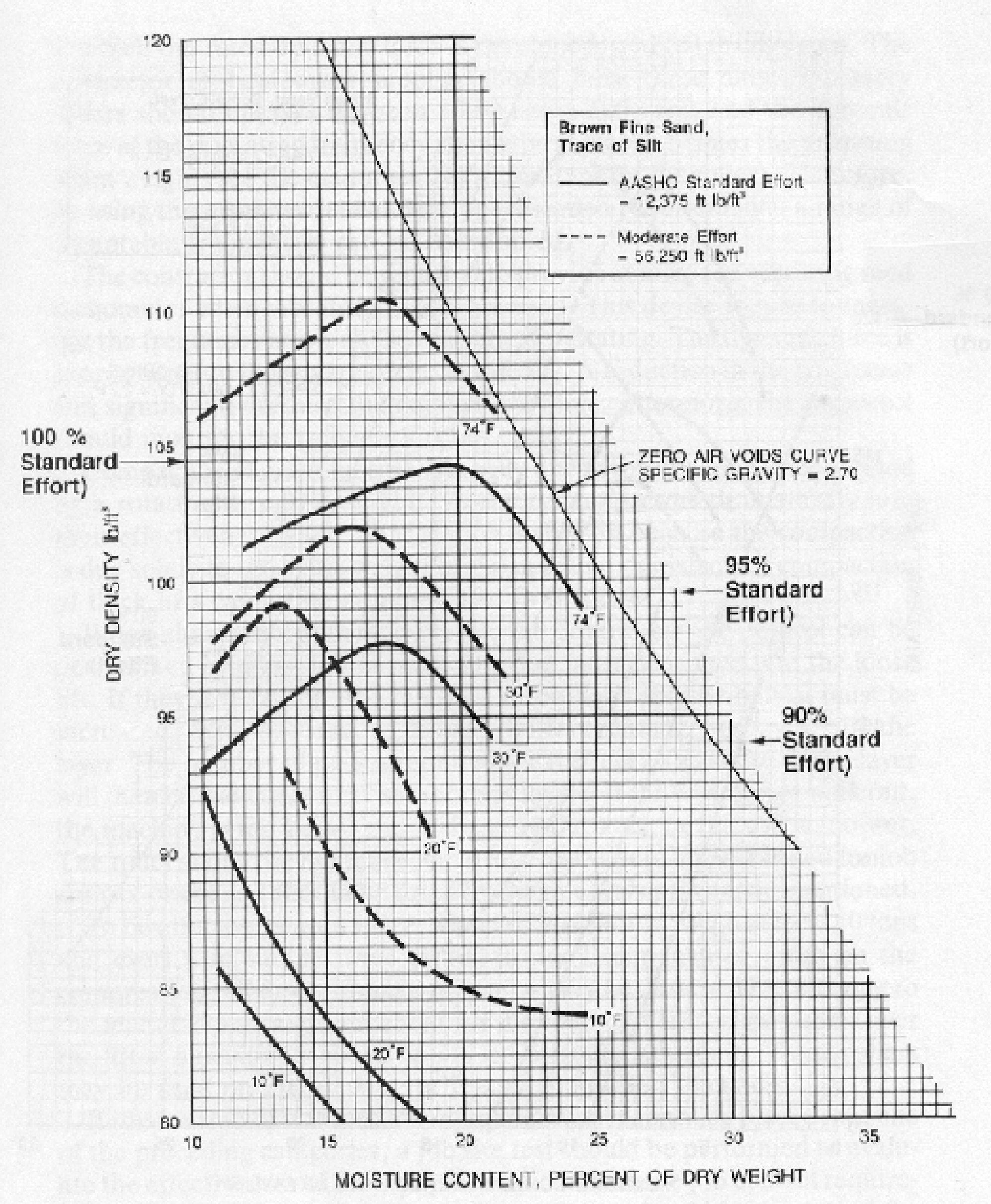


**FIGURE 4-1** Compaction control curves (standard and modified AASHTO) for a brown fine sand with a trace of silt at different temperatures (*courtesy W. P. Hofmann*).

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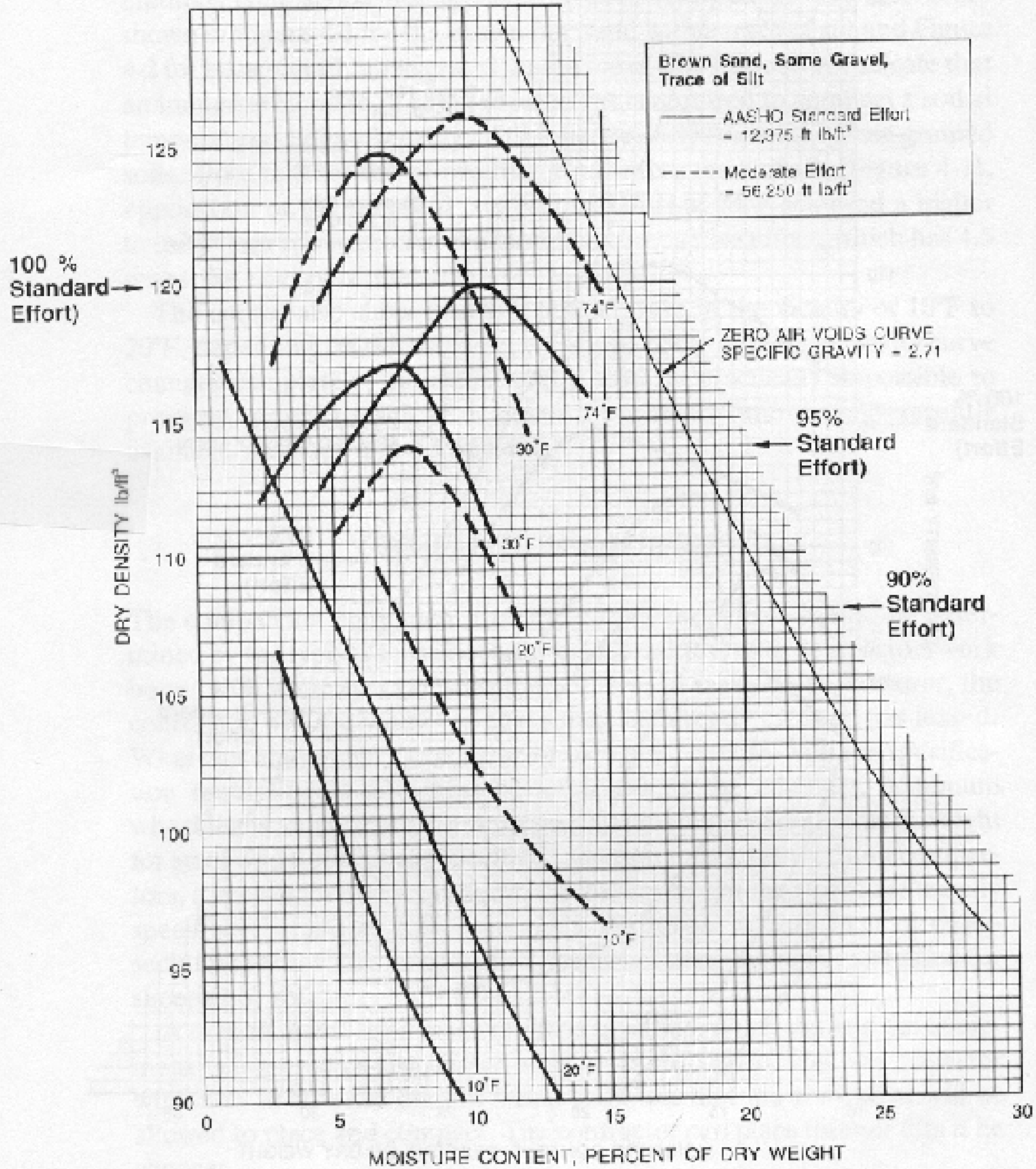


**FIGURE 4-2** Compaction control curves (standard and modified AASHTO) for a brown sand with some gravel and a trace of silt (*courtesy W. P. Hofmann*).

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# Helpful Hints

- Family of Curves
- One point proctors
- Field moisture content test
  - Dry back a sample
- Samples of Each Soil Type w/ known Proctor
  - Visual Comparison

# Family of Curves

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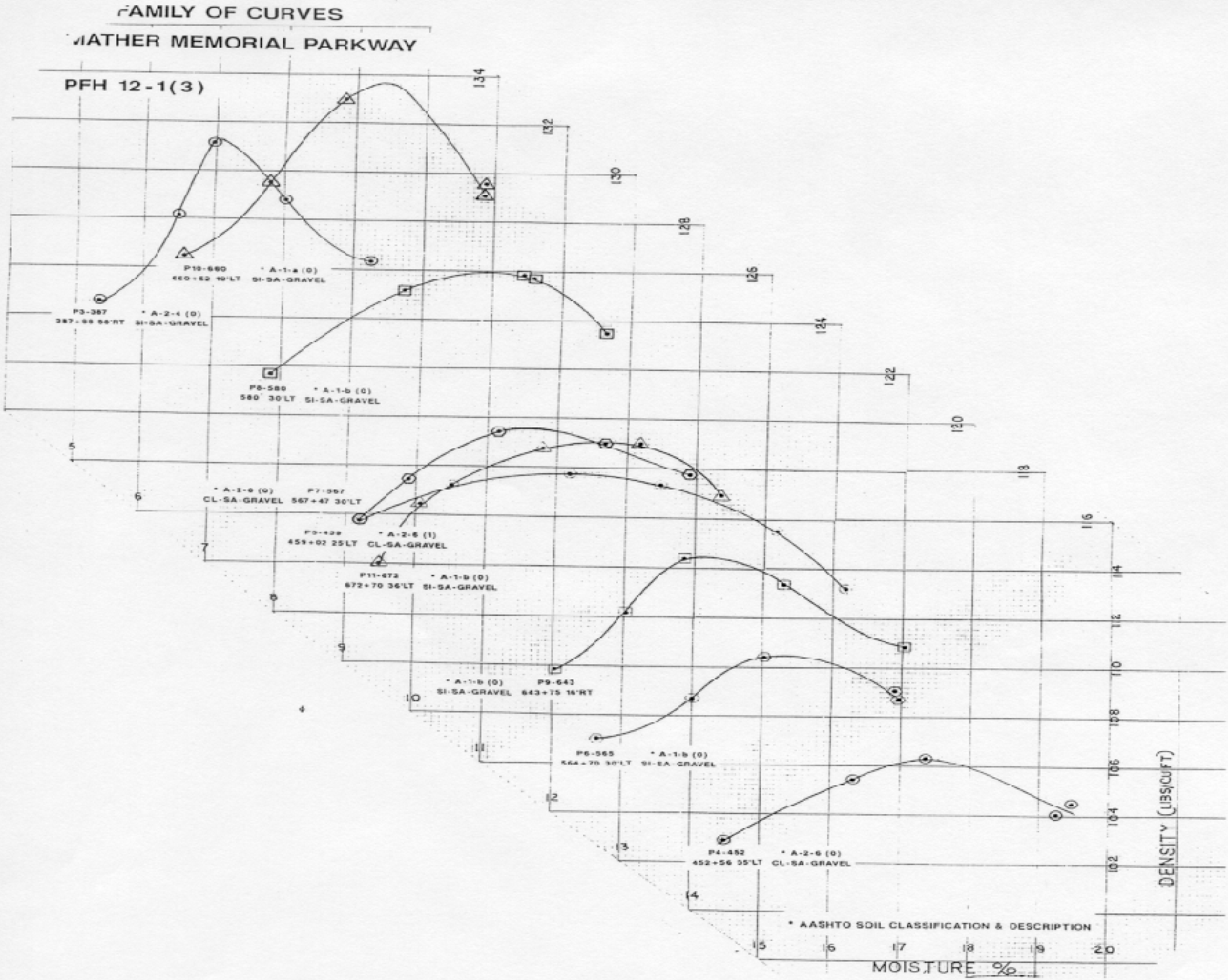

FAMILY OF CURVES
MATHER MEMORIAL PARKWAY
PFH 12-1(3)
P10-660
* A-1-a (0)
SI-SA-GRAVEL
P3-387
* A-2-4 (0)
SI-SA-GRAVEL
P8-580
* A-1-b (0)
580' 30'LT SI-SA-GRAVEL
* A-1-b (0)
P7-567
CL-SA-GRAVEL 567+47 30'LT
459+02 25'LT
* A-2-6 (1)
CL-SA-GRAVEL
P11-673
* A-1-b (0)
672+70 36'LT SI-SA-GRAVEL
* A-1-b (0)
P9-643
SI-SA-GRAVEL 643+75 14'RT
P6-565
* A-1-b (0)
P4-452
* A-2-6 (0)
452+56 35'LT CL-SA-GRAVEL
* AASHTO SOIL CLASSIFICATION & DESCRIPTION
MOISTURE %
DENSITY (LBS/CUFT)

# Compaction

- Subsection 204.11
- 3 methods to monitor compaction

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# Compaction – Method 1

- Coarse material
- 80% or more retained #4 sieve
- Roller passes
- Method specification

# Compaction – Method 2

- Combination of coarse and fine
- 50% to 80% retained #4 sieve
- “One rock in a bowl of soup”
- Check moisture of fines
- Method specification - Roller passes

# Compaction – Method 3

- Fine material with some coarse pieces
- 50% or less retained #4 sieve
- Classify material
- Perform compaction test
- Obtain 95% of maximum density

# Density Determination

- Sand Cone
- Balloon
- Oil (or water) Method
- Nuclear Densometer

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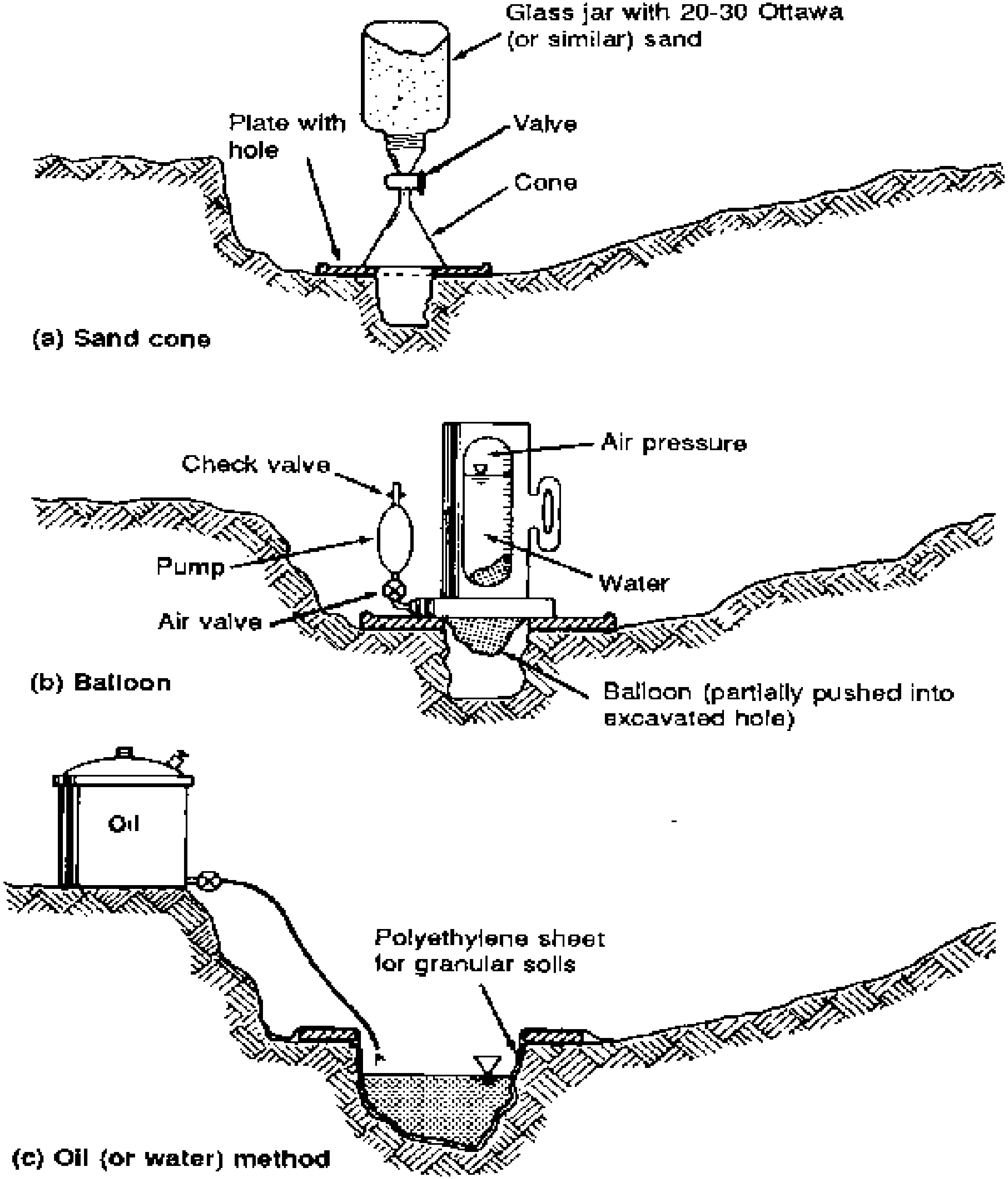


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# Nuclear Densometers

# AASHTO Test Methods

- AASHTO T 238 - Density of Soil and Soil- Aggregate In-place by Nuclear Methods

- AASHTO T 239 - Moisture Content of Soil and Soil-Aggregate In-place by Nuclear Methods

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# Calibration

- Check to make sure that the calibration certification is current.
- Determined by plotting the rate count given by the gage versus various known densities and moisture contents.
- Initially performed by the manufacturers.

# Standardization

Required at the start of each day's use or when test measurements are suspect.

- Warm up equipment according to manufacturer's recommendation
- Position on the "reference standard".
- Take at least 4 repetative readings at a minimum of 1 minute.
- Take the mean of the 4 readings.

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# Standardization - continued

- Insert the values into the following equation:
  - $N_s=N_o$ +/- 1.96 x Square root of $N_o$
  - $N_s$ - Count currently measured in checking the instrument operation on the reference standard.
  - $N_o$ - Count previously established on the reference standard (mean of 10 repetitive tests)
- $N_s$ must be within the bounds of the equation.

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# Standardization - continued

- If not within tolerance, repeat the standardization.
- If still not within tolerance, a calibration must be performed.

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# Methods and Procedures

- T-238 Density
  - Method A - Backscatter
  - Method B - Direct Transmission
  - Method C - Air Gap

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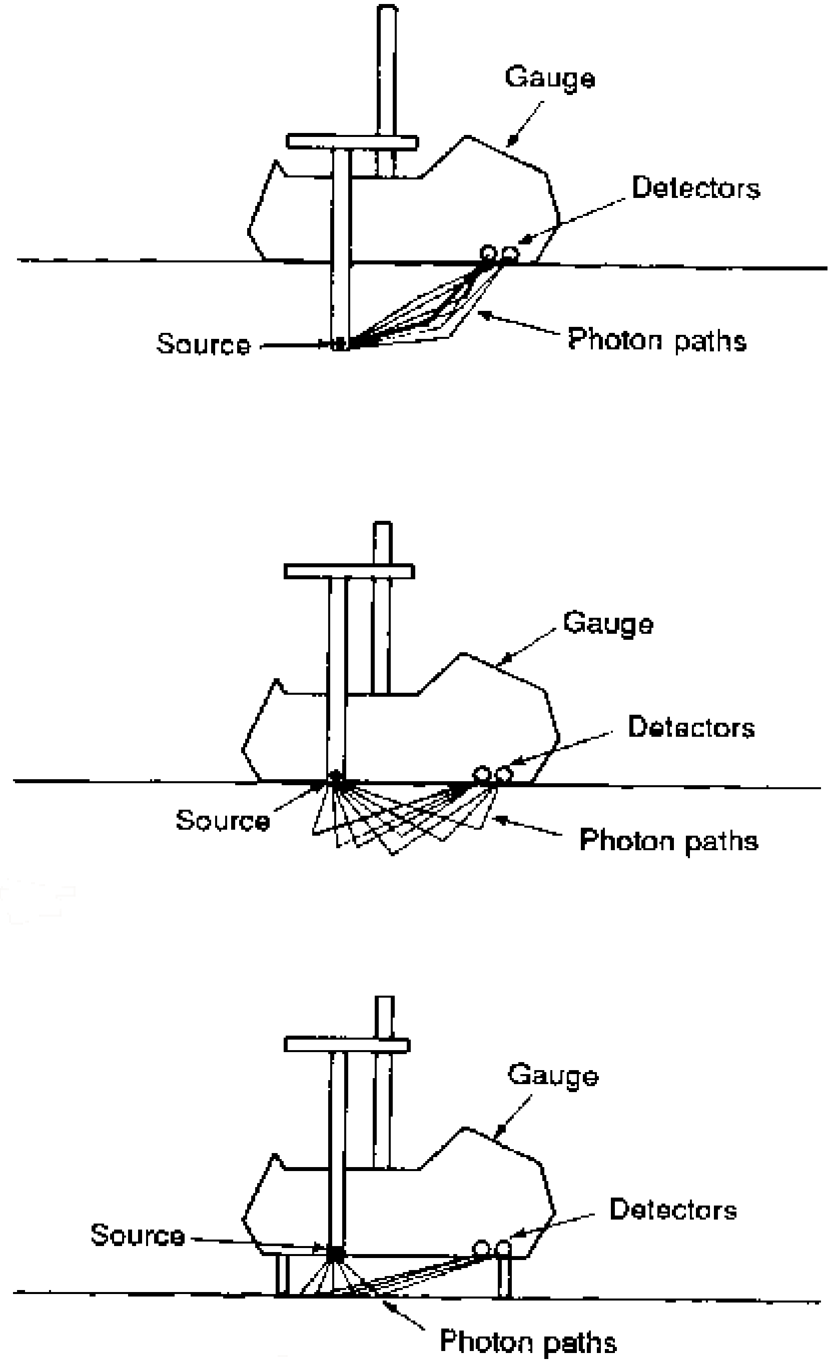


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# Backscatter – Method A

- Site preparation
  - Select location with a minimum of 150 mm clearance around gage from any vertical projection.
  - Remove all loose and disturbed material
    - Remove additional material as necessary to expose the top of the material to be tested.
  - Level the area as needed.
    - Sand or native fines may be used to fill voids greater than 3mm between gage and surface.

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# Backscatter – Method A

- Test
  - Place gage on the surface
  - Secure one or more 1 minute readings
    - If more than one reading is taken, average the results
  - Record the density information
  - Determine if the required density has been achieved based on the results of the proctor.

# Direct Transmission – Method B

- Prepare site similar to Method A.
  - Drive the pin through the guide to the necessary depth for testing.
    - Drive the pin slightly deeper than the test depth.
    - Maintain a minimum of 50 mm below the pin and the bottom of the lift to be tested.
  - Test Procedure same as Method A.


# Air Gap – Method C

- Prepare site similar to Method A
- Secure and record at least one or more 1-minute readings in the backscatter position.
- Place an air gap cradle, set at the optimum air gap as determined by the manufacturer, over the same area.

# Air Gap – Method C

- Determine the air gap ratio
- Air gap counts per minute / Backscatter counts per minute
- Determine the density by comparing it to the air gap calibration curve.

# T-239 Moisture Determination

- Procedures
  - Test performed concurrently with density tests
    - Backscatter or Direct Transmission Methods
  - Follow same site preparation techniques as the density test.

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# Calculations

- Average the readings
- Moisture Content - mass % of the dry soil
  - $w = (W_m / W_d) \times 100$
    - $W_m$ - Moisture content of soil
    - $W_d$ - Dry density of the soil

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# Report

- Location
- Elevation of surface
- Visual description of material
- Identification of test equipment
- Count rate for each reading
- Moisture content
- Wet density
- Dry density
- Moisture content in mass percent of dry soil

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# Comments on the "Nuke"

- Density should be within 40-80 kg/m3 (3-5 lb/ft3)
  - Without moving gage, within 16 kg/m3 (1 lb/ft3)
- Moisture content should be within 8-16 kg/m3 (0.5-1.0 lb/ft3)
  - Without moving gage, within 5 kg/m3 (0.3 lb/ft3)

***IF THE PROCEDURES ARE CAREFULLY FOLLOWED***

# Compaction Equipment versus Material

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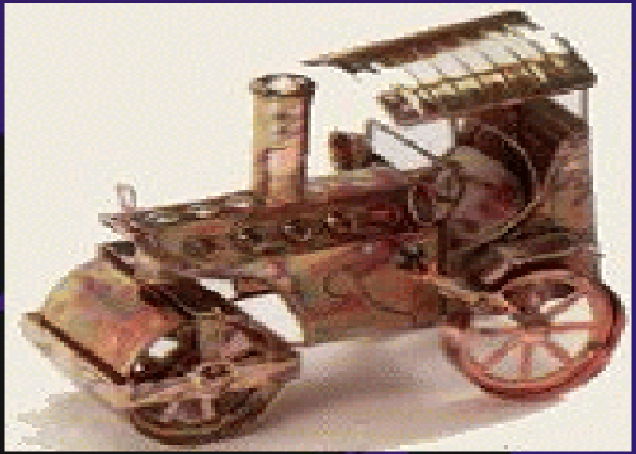
# Compaction Equipment

- Steel Drum Rollers
  - Works well in sands and fine granular materials.




# Compaction Equipment

- Steel Drum Rollers
- Impact Rollers (Sheep’s foot)
  - Works well in clays and high cohesion soils.

# Compaction Equipment

- Steel Drum Rollers
- Impact Rollers (Sheep's foot)
- Kneading Rollers (Pneumatic)
  - Works well in silty soils.

# Compaction Equipment

- Steel Drum Rollers
- Impact Rollers (Sheep's foot)
- Kneading Rollers (Pneumatic)
- Grid Rollers
  - Breaks down friable materials. (I.e., Tuff, Siltstone, Sandstone, Decomposed Granite)


# Compaction Equipment

- Steel Drum Rollers
- Impact Rollers (Sheep's foot)
- Kneading Rollers (Pneumatic)
- Grid Rollers
- Whackers

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# Compaction Equipment

- Steel Drum Rollers
- Impact Rollers (Sheep’s foot)
- Kneading Rollers (Pneumatic)
- Grid Rollers
- Whackers
- Trench Rollers


# Dealing with “Wet” Material

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# Dealing With “Wet” Material

- Drying It Out
  - How much effort is too much
  - Excessive Delays Due to Excess Moisture
- Methods
  - Scarify, Windrow, Spread-out and Dry
  - Blending with Dry Material
  - Waste it
  - Others??

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# Dealing With “Wet” Material

- Preventative Techniques
  - Shape areas to prevent ponding water
    - FP-96 specification 204.06 & 204.10(a)
  - Direct water away from material
  - “Stir” Material Piles or cover with tarps
  - Cut ditches and install drainage devices whenever possible
    - Culverts, underdrains, edgedrains, etc.

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# Pumping

- Elastic deformation of the soil
  - When loaded and released, the soil springs back to its original position.
- Cause
  - Excess moisture
    - Not enough time to dry as a load is applied.
- Easiest solution
  - Allow the area to dry which will allow the excess pore water pressure to dissipate.
  - Use lighter compaction equipment
- If not corrected, may lead to rutting.

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# Rutting

- Cause
  - Surface shear or bearing failure of the soil.
- Solutions
  - Change methods
    - operation
    - materials
    - loading

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# Go To Lunch!

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